

## **THREE-DIMENSIONAL CORRELATED DATA DISPLAY**

### **FIELD OF THE INVENTION:**

The present invention relates to the field of graphic visualization tools  
5 and, more particularly, to three-dimensional representation of multi-domain  
measurements of system operation.

### **BACKGROUND OF THE INVENTION**

Signals acquired from relatively simple systems can be viewed and  
10 understood using two-dimensional graphing techniques that represent electrical  
activity one or more nodes in a circuit under test. Testing of more complex  
systems requires that many nodes (often hundreds) be viewed, and the  
information content and different timing relationships of these signals must be  
presented to the user.

15 A problem arises because different measurement instruments are used to  
gather information in different measurement domains, and each measurement  
domain provides a different view of circuit activity over time. For example, an  
oscilloscope provides representations of electrical phenomena associated with a  
circuit node, a logic analyzer provides representations of information content  
20 (i.e., logic level and transition timing) on a (typically) related set of nodes, and a  
spectrum analyzer represents the intensity or energy associated with each of a  
plurality of frequency components. Unfortunately, it can be difficult for a user to  
correlate information derived from each of the measurement domains to arrive at  
a higher level of understanding of the operation or failure of a system under test.

25 What is needed is a method and apparatus for combining the  
measurement results from the different measurement domains into a correlated,  
and easy to understand display.

### **SUMMARY OF INVENTION**

30 These and other deficiencies of the prior art are addressed by the present  
invention of a method and apparatus for a synchronized presentation of multi-  
domain measurements using an actual or quasi 3-D representation.

A method according to one embodiment of the invention comprises receiving a plurality of sample streams representing respective signal measurements; temporally aligning the sample streams; generating waveform data associated with the temporally aligned sample streams, the waveform data representing sample magnitudes as a function of time and including Z-axis information adapted to illustrate at least one inter-stream timing relationship.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIGURE 1 is a high level block diagram of a signal analysis and display system according to an embodiment of the invention;

FIGURE 2 is a flow diagram of a method according to an embodiment of the invention; and

FIGURES 3, 4, and 5 are graphical representations useful in understanding the present invention.

FIGURES 6 and 7 are illustrations of screen displays in accordance with the invention.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the FIGURES.

#### DETAILED DESCRIPTION OF THE INVENTION

The subject invention will be primarily described within the context of a signal acquisition system having a plurality of function modules where each function module performs a respective different signal processing and/or analysis function. However, it will be appreciated by those skilled in the art that the various function modules may be used to implement any combination of functions, including multiple instances of the same function. It will further be appreciated by those skilled in the art that the invention may be advantageously employed in any environment where multiple signal acquisition and/or analysis devices process signals under test, wherein a common correlated display of

information derived from such processing is useful. Thus, even though FIGURE 1 shows a system incorporating a plurality of function modules, the various function modules may be dispersed or otherwise provided by additional test and measurement instruments for acquisition of data samples by the various test  
5 and measurement instruments.

To achieve a multi-domain measurement display, embodiments of the present invention utilize a common time reference between the various measurement domain instruments such that an inter-stream timing relationship is established to enable a 3-D or quasi 3-D waveform representation of the  
10 measurements performed by the various instruments. These measurements must then be presented to the engineer in a manner that more readily allows the presented measurement information to be integrated into a meaningful analysis. In this manner, a user may gain insight into the cause and effect relationships in the operation or failure of the system under test.

FIGURE 1 is a high level block diagram of a system according to an embodiment of the present invention. Specifically, the system **100** of FIGURE 1 comprises an optional input selection machine **110**, a plurality of signal analysis functions **120<sub>1</sub>-120<sub>N</sub>** (collectively signal analysis functions **120**), a time base **130**, a trigger controller **140**, an input device **150**, a presentation device **160**, and a  
20 controller **170**.

Each of the signal analysis functions **120** comprises any one of a digital storage oscilloscope (DSO) function, a logic analyzer function, a network analysis function, a spectrum analysis function, and the like. Each of the signal analysis functions **120** receives a corresponding input signal **IS<sub>1</sub>-IS<sub>N</sub>** for  
25 processing, which processing results in a corresponding output stream **OS<sub>1</sub>-OS<sub>N</sub>**. Thus, the first input signal **IS<sub>1</sub>** is processed by first signal analysis function **120<sub>1</sub>** to produce first output stream **OS<sub>1</sub>** and so on up to an Nth signal analysis function **120<sub>N</sub>** processing an Nth input signal **IS<sub>N</sub>** to produce an Nth output stream **OS<sub>N</sub>**. It should be noted that a single input signal **IS** may be used to  
30 drive one or more of Signal Analysis Functions **120**. It will be noted that each of the input signals **IS<sub>1</sub>-IS<sub>N</sub>** may comprise one or many respective input signals though it is represented by a single arrow in FIGURE 1. For example, in the case of a signal analysis function **120** comprising a logic analyzer, the

corresponding input signal may comprise dozens or hundreds of actual input signals.

Each of Signal Analysis Functions **120** is responsive to a trigger signal **TRIG** produced by Trigger Controller **140** and a time base signal **TIME** produced  
5 by Time Base Controller **130**. Thus, the data acquisition and analysis functions provided by the various Signal Analysis Functions **120** may be synchronized and commonly triggered as desired. In this manner, the resulting output data streams **OS<sub>1</sub>-OS<sub>N</sub>** provide temporally-related data which may be aligned in time to support a temporally-synchronized display of data from each of a plurality of  
10 measurement domain instruments.

Optional Input Selection Module **110** is capable of receiving a plurality of signals under test **SUT<sub>1</sub>-SUT<sub>x</sub>** (collectively signals under test **SUT**). Optional Input Selection Module **110**, in response to a control signal ISMC provided by Controller **170**, couples any of the input signals under test **SUT<sub>1</sub>** through **SUT<sub>x</sub>**  
15 to any of Signal Analysis Functions **120<sub>1</sub>-120<sub>N</sub>** as corresponding input signals **IS**. Optional Input Selection Module **110** is useful where many signals under test are to be switched or where multiple Signal Analysis Functions **120** receive common signals under test. Where a predetermined coupling of signals under test to Signal Analysis Functions **120** is known (and unvarying), then such coupling  
20 may be made directly without use of Optional Input Selection Module **110**.

The Controller **170** controls the operation of Signal Analysis Functions **120**, Time Base Controller **130**, Trigger Controller **140** and, Optional Input Selection Module **110**, if present. Controller **170** comprises a Processor **176** and a Memory **178** for storing various control programs and other programs **178-  
25 P** as well as data **178-D**. Memory **178** may also store an operating system **170-OS** such as the Windows® operating system manufactured by Microsoft Corporation of Redmond, Washington. Other operating systems, frameworks and environments suitable for performing the tasks described herein will also be appreciated by those skilled in the art and informed by the teachings of the  
30 present invention. For example, Apple®, MacIntosh® operating systems, various UNIX-derived operating systems and the like also support functions such as those discussed herein.

Processor **176** cooperates with conventional Support Circuitry **174** such as power supplies, clock circuits, cache memory and the like, and circuits that assist in executing software routines stored in Memory **178**. As such, it is contemplated that some of the steps discussed herein as software processes  
5 may be implemented within hardware, for example as circuitry that cooperates with Processor **176** to perform various steps. Controller **170** also contains I/O(input-output) Circuitry **172** that forms an interface between the various functional elements communicating with Controller **170**. For example, I/O Circuitry **172** allows Controller **170** to communicate with each of the other  
10 elements 110-160 discussed herein with respect to FIGURE 1.

Although Controller **170** is shown and described as a general purpose computer, programmed to perform various control functions in accordance with the present invention, the invention can be implemented in hardware as, for example, an application specific integrated circuit (ASIC) or field programmable  
15 gate array (FPGA). As such, the process steps described herein are intended to be broadly interpreted as being performed by software, hardware or a combination thereof.

Input Unit 150 comprises a keypad, a pointing device, a touch screen or other means adapted to provide user input to Controller **170**. Controller **170**, in  
20 response to such user input, adapts the operation of System **100** to perform various functions including data acquisition, triggering, processing, display, and communications. In addition, the user input may be used to trigger automatic calibration functions and/or adapt other operating parameters of Signal Analysis Functions **120**, such as DSO (digital storage oscilloscope) functions, logic  
25 analysis functions, spectrum analysis functions and the like.

Controller **170** processes one or more acquired sample streams provided by Signal Analysis Functions **120** to generate respective waveform data associated with the one or more sample streams. For example, given desired time per division and volts per division display parameters associated with a  
30 DSO signal analysis function stream, Controller **170** operates to modify the raw data associated with the DSO sample stream to produce corresponding waveform data having the desired time per division and volts per division parameters. Controller **170** may also normalize waveform data having non-

desired time per division and volts per division parameters to produce waveform data having the desired parameters. Controller **170** provides the waveform data to Presentation Device **160** for subsequent display. Presentation Device **160** may comprise a conventional display device such as a liquid crystal display (LCD), cathode ray tube (CRT) or other display device. Presentation Device **160** may include respective processing, input/output and memory functions such that video signals adapted to produce imagery upon the presentation device **160** may be provided by Controller **170** or, alternatively, generated by the presentation device **160** in response to non-video signals provided by Controller **170**.

System **100** of FIGURE 1 denotes a generalized representation of an actual system. For example, in one embodiment of the invention one signal analysis function comprises a DSO, another comprises a logic analyzer and a third comprises a spectrum analyzer. Thus, in this embodiment of the invention, only three of Signal Analysis Functions **120** are used and, correspondingly, an appropriate number of signals under test (**SUT**) are provided thereto.

Each of the sample streams acquired by System **100** of FIGURE 1 is stored as a respective plurality of sample records, where a sample record may comprise a single sample point or a plurality of sample points. The sample records may be increased or decreased in size and may be scaled according to the memory requirements or availability of the system. Within the context of the subject invention, temporal alignment is used to align sample streams acquired from test and measurement instruments monitoring a plurality of measurement domains. Waveform imagery generated using the acquired sample streams may be aligned as image layers on a common XY plane where a Z axis perpendicular to the one or more image planes is used to provide imagery representing signals of an additional measurement domain or a mathematical processing of one or more of the measurement domains of interest. Coplanar waveform imagery will be discussed in more detail below with respect to FIGURES 3-5. It will be noted that the coplanar imagery discussed with respect to FIGURES 3-5 may also include more or fewer waveforms than shown, as well as more or fewer image planes than shown.

System 100 of FIGURE 1 finds practical application in many test and measurement scenarios. For example, in one scenario an oscilloscope, a logic analyzer and a spectrum analyzer are used to measure or characterize the operation of a computer interface, such as a Bluetooth channel, a WiFi channel or an Ethernet channel. The techniques discussed herein are also applicable to other communications media and methodologies, such as satellite channels, hybrid fiber coax channels, a wireless LAN channels and the like. The radio frequency (RF) domain is monitored by the spectrum analyzer to identify noise or other spectral anomalies that might be disruptive to data flow via the wireless computer interface. The analog domain is monitored by the oscilloscope to view the modulated logic signal that is being transmitted via the wireless computer interface. The digital domain is monitored by the logic analyzer to examine the digital packets that are reconstructed after reception via the wireless computer interface. One skilled in the art will quickly realize that the subject invention is extremely useful for clearly showing the relationship between measurements from all three measurement domains.

For example, it is useful to identify, or at least view, the relationship between a noise spike occurring in the RF domain and a packet error occurring in the digital or information domain. To facilitate such analysis, the subject invention renders these three complex domains in a manner that is readily accessible to a viewer. That is, the acquired sample streams representing measurements made in the three domains are temporally aligned and combined to provide waveform data in which analog and digital domain information are displayed within the XY coordinate system of an oscilloscope display, while spectral information is displayed on the Z-axis. Other use of the XYZ coordinate systems may also be employed. Of particular use is the ability to render a manipulable two-dimensional or three-dimensional display in which waveform data drive from each of the three domains is represented.

Thus, as discussed herein, one embodiment of the invention is the application of three-dimensional representation of multi-domain measurements of system operation in which one or more of an oscilloscope graph, a logic analyzer trace, a packet representation and a frequency spectrum waterfall image are combined into a single three-dimensional display with one axis being

time, a second being measurement domain, and a third being intensity or content of the measured phenomena. The tools of three-dimensional graphics are applied to provide viewing position, perspective and artificial colorization or intensity gradation to highlight areas of interest.

5           Three-dimensional representation may be provided using holographic imagery, binocular vision and other techniques. Similarly, a third dimension may be represented using a two-dimensional display such as a perspective or isometric view. The two-dimensional representation may be fixed in perspective or manipulable by a user. By providing multiple domain waveform  
10 representations, inter-stream timing relationships, such as the timing relationship between a noise spike and a data correction in the above example, may be established and displayed.

FIGURE 2 shows a flowchart of a method according to an embodiment of the invention. Specifically, the method **200** of FIGURE 2 is entered at step **210**  
15 when acquired streams of data are received. The acquired streams of data may be received from, per box **215**, oscilloscopes, logic analyzers, spectrum analyzers and other test and measurement devices and/or sources.

At step **220**, the acquired data streams are temporally aligned so that inter-stream timing relationships are established. That is, by temporally-aligning  
20 the acquired data streams, a viewer examining a subsequently rendered 2-D or 3-D representation of the waveforms may visually establish that an anomaly or event represented in one measurement domain is temporally-associated with a corresponding anomaly or event within another measurement domain. Per box **225**, time stamping, trigger synchronization, a common clock, or other timing  
25 means provides the basis for temporal alignment of the measurements across the domains. In a time stamping embodiment, respective time stamps are inserted periodically, or provided contemporaneously with, each acquired data stream. The time stamps provide an indication of the acquisition time or other timing parameter (e.g., real time, trigger offset time, and the like). The time  
30 stamps are used to perform the temporal analysis function of step **220**. In an alternate embodiment, a trigger synchronization scheme is used whereby each of the test and measurement devices (e.g., oscilloscope, logic analyzer, spectrum analyzer and the like) operate in response to a common trigger signal.



The common trigger signal may be any triggering event and may be generated using digital or analog means. The triggering signal may be representative of a glitch, a runt signal (i.e., a signal having a less than acceptable amplitude), or other predetermined condition, transition, or anomaly, as well as an  
5 arrangement of data bits matching a desired sequential or combinatorial logic pattern. In an alternate embodiment, a common clock signal is used such that all of the test and measurement devices acquiring streams of data are synchronized. The time stamp, common trigger and common clock embodiments may be used individually or in any combination. It will be  
10 appreciated by those skilled in the art and informed by the teachings of the present invention that various buffering, delay and hold-off circuitry or control functions may also be employed to insure that system delays, acquisition delays and the like are compensated for as part of the temporal alignment process of step 220.

15 At step 230 the temporally-aligned data streams are combined and rasterized to provide waveform data suitable for display in three dimensions. The rasterization process used depends upon the type of display device employed to present the waveform data. For example, rasterization appropriate to a two-dimensional display such as a liquid crystal display or cathode ray tube  
20 may not be appropriate to the rasterization requirements of a holographic image, stereoscope image or other three-dimensional display technique.

At step 240 the waveform data is displayed according to, per box 245, a two-dimensional or three-dimensional display technique. Two-dimensional techniques include perspective control, orthogonal view (i.e., stacked display of  
25 waveforms) and other display techniques simulating a three-dimensional display. Three-dimensional display techniques comprise holographic images and other true three-dimensional renderings.

The display of the time-aligned waveforms according to the invention may be modified in many different ways. For example, rather than using a Z-axis  
30 representation, waveforms representative of a third measurement domain or a waveform associated with an inter-stream timing relationship may be represented by changes in intensity or color of the waveforms represented in the XY axis. For example, where energy associated with a particular spectral region

is relatively high, a temporally-aligned signal acquired from the analog domain or digital domain contemporaneous with measurements made in the high energy RF domain may be displayed with a higher intensity level or different color level.

At step 250, the waveform data for display is adapted in response to user manipulation. For example, a two-dimensional orthogonal (i.e., "stacked") display simulating a three-dimensional display may be translated into a perspective view of the displayed waveform data, by user manipulation of an XYZ vector icon. Similarly, a waveform display having a three-dimensional perspective view may be adapted (i.e., translated or rotated) by a user, as desired.

FIGURES 3, 4, and 5 are graphical representations of screen displays useful in understanding the present invention. FIGURE 3 shows a screen display of two precisely time-aligned, overlapped (i.e., "stacked") sine waves. In such a display, it can be said that a Z-axis is present, but provides no viewing perspective to a user because the Z-axis of the display is perpendicular to the user's field of view. The two overlapping sine waves of FIGURE 3 become distinct when the viewing perspective is "tilted" as shown in FIGURE 4. Thus, the XY coordinate representation shown in FIGURE 3 becomes an XYZ coordinate representation in FIGURE 4, by translating one of the screen displays in the X and Y axes with respect to the other screen display. Similarly, the screen display of FIGURE 3 can be transformed into a perspective view by use of well-known graphical image rotation methods. FIGURE 5 is a composite representation of a repetitive pulse signal and a sine wave signal having a perspective view similar to that of FIGURE 4 such that additional spatial separation is provided.

FIGURE 6 shows a screen display in perspective view in accordance with the subject invention. In FIGURE 6, the X-axis represents TIME, the Y-axis represents MAGNITUDE, and the Z-axis represents DOMAIN. Specifically, waveform 610 is a waveform captured from the Analog Domain, waveform 620 is a waveform captured from the Logic Domain, and the area generally-designated 630 contains spectra 630a, 630b, 630c, 630d, 630e, and 630f captured from the Frequency Domain. Only seven spectra were shown in FIGURE 6 to avoid cluttering the drawing for purposes of clarity. In fact, a

spectrum exists at each point in time that corresponds to a sample point. . All available spectra may, or may not, be displayed simultaneously depending upon the particular data to be highlighted.

Note the substantially simultaneous appearance of a "glitch" **615** on  
5 analog waveform **610**, a signal anomaly **625** on logic waveform **620**, and a spurious trace (i.e., a "spur") **635** in the spectrum **630d**. In such a case, it may be desirable to display only the single spectrum **630d** that shows the spur.

FIGURE 7 is an orthogonal screen view showing the same information as the perspective view of FIGURE 6. In FIGURE 7, the X-axis represents TIME,  
10 the Y-axis represents MAGNITUDE for the Analog Domain waveform **710** and the Logic Domain waveform **720**, but represents FREQUENCY for the spectra of the Frequency Domain. In FIGURE 7, the Z-axis applies to the Frequency Domain only, and is arranged such that it is perpendicular to the screen display and pointed directly toward the viewer. Thus, the spectra **730a** through **730f** are  
15 rotated such that viewer is looking directly down the Z-axis onto the tops of the individual energy spikes. In this example, the relative magnitudes of each of the energy spikes is shown by color (denoted by different cross hatching). Note that the spur **735** is more readily observable in the example of FIGURE 7 than it is in the example of FIGURE 6. In the examples shown in both FIGURES 6 and 7  
20 the spur is substantially the same magnitude as the center frequency component. Note also that the dotted line shows that spectrum **730d** is time-aligned with glitch **715**, and anomaly **725**.

As discussed above with respect to FIGURE 6, only seven spectra were shown in FIGURE 7. If all of the spectra were shown in FIGURE 7, the spectra  
25 would be packed together so closely that area **730** would appear as solid multi-colored sheet. It is herein recognized that such a display may be very useful, because the human eye is quite good at discerning different areas of differing color.

In one embodiment of the invention, the viewer or user may highlight  
30 contemporaneous or temporally aligned portions of each of the measurement domain waveforms to establish an area of interest, which area of interest may be magnified or "zoomed in" to allow more detailed examination of the waveforms. Moreover, other oscilloscope waveform processing functions such

as mathematical functions may be employed to process the various waveforms and drive thereby additional information useful to the test and measurement instrument user. For example, in response to a primary or secondary trigger condition existing in one of the measurement domains, a mathematical function  
5 may be employed to process contemporaneously acquired or relevant samples from another measurement domain.

While the foregoing is directed to the preferred embodiment of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope of the  
10 invention is determined by the claims that follow.